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by

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I. Introduction

The diffusion of cost reducing processes and particularly the widespread adoption of the Basic Oxygen Process (BOP) have recently been studied extensively.[1] One reason for this interest is based on the fact that the BOP reduces capital costs in steelmaking by one half and labor costs by one third,[2] and the allegedly slow rate of acceptance of the BOP in the U.S. steel

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[1]The most thorough examination of the determinants of the diffusion of innovations has been by Edwin Mansfield, Industrial Research and Technological Innovation (New York: Norton, 1968), Chapters 7-9. See also Walter Adams and Joel B. Dirlam, "Big Steel, Invention and Innovation," Quarterly Journal of Economics, LXXX (May, 1966), pp. 167-89, and G. S. Maddala and P. T. Knight, "International Diffusion of Technical Change - A Case Study of the Oxygen Steel Making Process," Economic Journal, LXXVII (September, 1967), pp. 531-58. After this study was already under way I was made aware of the work by J. R. Meyer and Guy Herregat, "The International Diffusion of the Basic Oxygen Steel Process," National Bureau of Economic Research, April, 1971, mimeographed.

[2]Detailed data on costs are given by Adams and Dirlam, op. cit., pp. 178-81 and Maddala and Knight, op. cit., pp. 537-40.

industry has been viewed as a contributory cause of relatively high U.S. prices for steel products. Moreover, the level of diffusion of the BOP of a sample of countries appears to be significantly related to another aspect of economic performance, namely, their net trade balance in steel products.[3] This empirical evidence leads to the conclusion that the more fundamental causes of comparative cost differences in a dynamic world are to be found among the determinants of the rate of diffusion of new techniques.

The determinants of the diffusion of a capital embodied technical change such as the BOP fall into the following categories: i) the age of the capital stock and the amount of investment in the industry; ii) relative factor prices; iii) the profitability of the new process under different economic conditions; iv) the internal competitive pressure from within industry and v) the external competitive pressure from imports. In subsequent sections of this paper variables which reflect these determinants will be specified and then related to the diffusion of the BOP in the United States and Canada in a time series analysis. It will be shown that previous research in this area has provided an incomplete picture because: a) conditions which make the BOP more profitable in one country as compared with another have not been carefully analyzed and b) specific differences in the market structure of the steel industry from one country to the next have been largely ignored. However, before turning to the specification and empirical testing of the model, it is desirable to examine the data on the diffusion of the BOP.

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[3]David Ault, "The Determinants of World Steel Exports: An Empirical Study," Review of Economics and Statistics, 54 (February, 1972), pp. 38-46. The importance of finding the determinants of the rate at which known technical innovations will be adopted has been underlined by E. H. Phelps Brown, "The Underdevelopment of Economics," Economic Journal, 82 (March, 1972), p. 5.

II. The Diffusion of the BOP in the U.S. and Canada, 1955-71

In their pathbreaking study Adams and Dirlam concluded that i) the United States lagged in the adoption of the BOP and ii) the major U.S. steel companies were the cause of this performance because of their reluctance to commit themselves to the new technique.[4] However, critics of Adams and Dirlam argued that there were objective economic factors which explain the decision of large U.S. steel producers to remain wedded to the older Open Hearth (OH) method.[5] The validity of these explanations will be considered in Section IV. Still other researchers have taken the view that the U.S. did not lag in the adoption of the BOP.[6] This confusion arose in part because reference to a particular year or sub-period can lead to widely different conclusions. From Chart 1, it is apparent that both Canada and the United States started producing steel with the BOP method at the same time, but that Canada had a higher rate of diffusion of the BOP until the early 1960's. In the United States, the rate of diffusion was slow until 1963, but after that date it increased and by 1968 the American level of diffusion exceeded the Canadian level. The almost constant level of diffusion of the BOP after 1962 in Canada is to some extent misleading since two additional BOP steelmaking plants are

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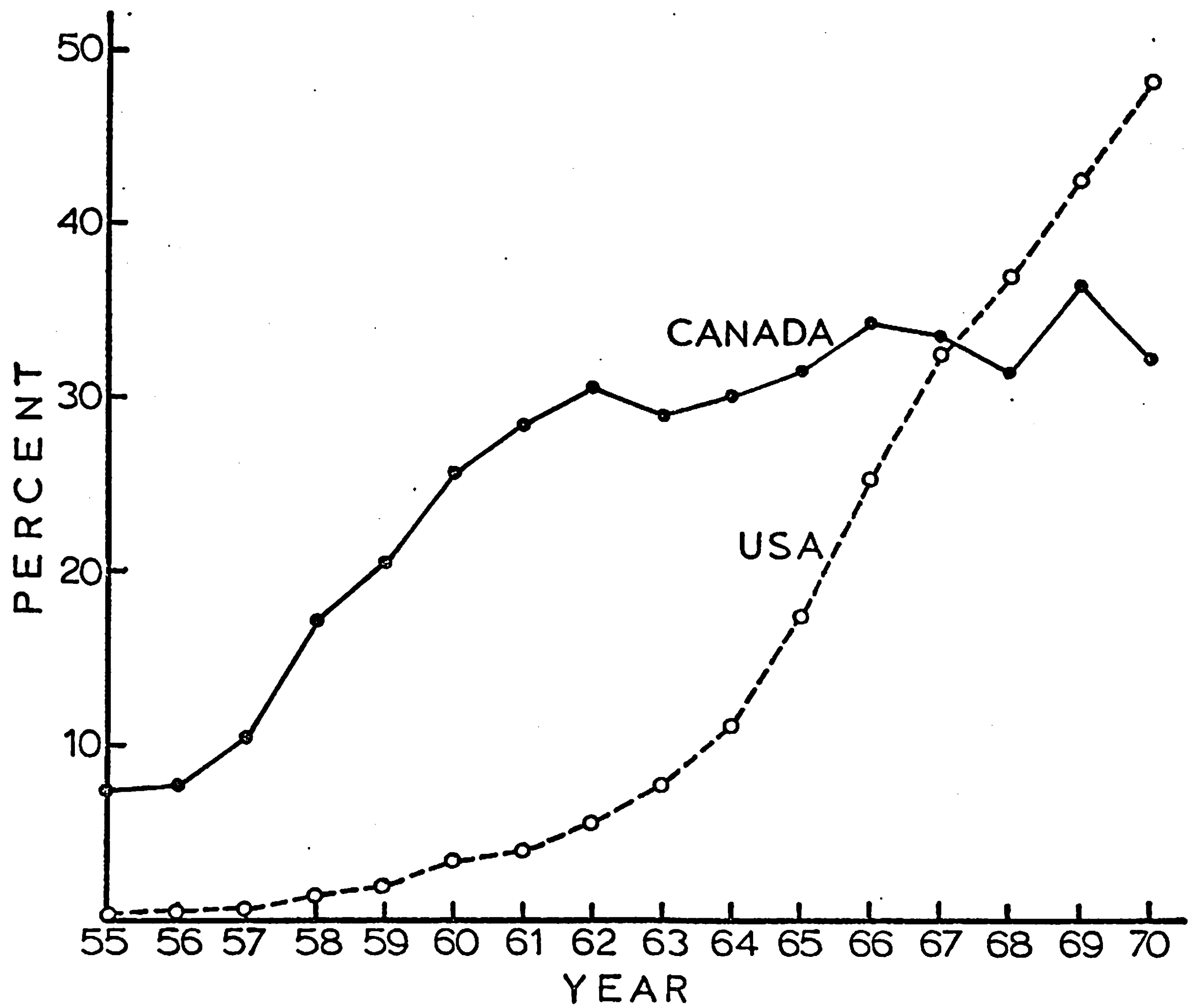
[4] Adams and Dirlam, op. cit., pp. 188-89.

[5] McAdams, A. K., "Big Steel, Invention and Innovation, Reconsidered," Quarterly Journal of Economics, LXXXI (August, 1967), pp. 457-74.

[6] Maddala and Knight, op. cit., p. 548, and discussion pp. 5-6, below.

Chart 1 - PERCENTAGE SHARE OF BOP OUTPUT IN TOTAL STEEL INGOT OUTPUT



SOURCE: For Canada, Department of Energy,Mines and Resources, Primary Iron and Steel, Ottawa, selected issues. For the U.S., American Iron and Steel Institute, Annual Statistical Report, 1955-1970.

scheduled to go into operation during 1972, and thus both countries are rapidly moving toward the equilibrium level of diffusion of the BOP which has been estimated to be 80% of total steel production.[7] As this discussion and Chart I suggest, the supporters of the technological performance of the U.S. steel industry base their analysis on the post-1963 period while the critics of the U.S. steel industry take 1955 as their starting point.

A more subtle problem is involved in the findings of Maddala and Knight who classify both the U.S. and Canada among the leaders in BOP adoption. They base their conclusion on data from the 1956 to 1964 period which indicate that the ratio of increase of BOP steel production to the total increase of steel production was over 50% for both countries.[8] According to this criterion, the United States ends up as the country with the most rapid adoption of the BOP for steelmaking in the above period, but this result reflects the fact that while other countries were increasing their steel production with techniques such as the OH furnace, the U.S. was reducing her steel production with alternate techniques. The misleading picture which results from the Maddala and Knight criterion can be illustrated with the following chain of reasoning. Assume that the dominant U.S. firms set the price of steel products to reflect costs, and recall that the major U.S. firms did

[7] On January 1, 1972 Canadian BOP capacity (not output) was estimated to be 43.5% of total steel capacity while an appropriate guestimate for January 1, 1973 would appear to be 56.3%. These calculations are based on information from Department of Energy, Mines and Resources, Primary Iron and Steel, Operators List 1, Part 1, Ottawa, January 1972. Steel for special purposes is also produced by electric reduction method, and this will continue to be the case. Hence, the BOP will never be the only type of steel furnace in use.

[8] Maddala and Knight, *op. cit.*, p. 547.

not adopt the cost reducing BOP during the 1950's. This would improve the relative cost, and hence price competitiveness of foreign producers which adopted the BOP. Imports of steel products to the U.S. would increase, and the production of steel in the United States would be reduced. Subsequently, under the pressure of foreign competition the U.S. industry adopts new BOP technique, and by 1964 a large increase of BOP steel production relative to total steel production has been achieved. In addition, it has been argued that the major U.S. firms assume a low price elasticity of demand for their products. This would make them reluctant to cut prices as capacity utilization fell. Since capacity utilization in the early 1960's was quite low, there would be a tendency to idle plants with high variable costs, i.e., older OH steelmaking plants and this would give an upward bias to the Maddala and Knight criterion for the U.S. or any country with low rates of capacity utilization.

These scenarios suggest that the ratio of BOP steel to total steel products[9] from the first year of adoption of the new method should be considered in order to establish the particular time pattern of adoption. Moreover, the rate of adoption of a new technique during its early life may be particularly important because leads and lags in process innovations among countries may have an important bearing on cost competitiveness and the net trade balance.[10]

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[9]The present paper relies on output (production) data rather than capacity data for different types of steel furnaces because capacity data are not readily available for the United States after 1965.

[10]This idea is derived from the product cycle literature. See Raymond Vernon, "International Investment and International Trade in the Product Cycle," Quarterly Journal of Economics, LXXX (May, 1966), pp. 190-207, and J. E. Tilton, International Diffusion of Technology: The Case of Semiconductors, (Washington: Brookings, 1971). However, in the semiconductor industry product and process innovations occur simultaneously. For a detailed treatment of the role of BOP adoption on bilateral trade consult my "Relative Competitiveness of the U.S. and Canadian Steel Industries, 1954-70," unpublished paper, October, 1972.

III. A Model of the Diffusion of the BOP

In accordance with the arguments made above the level of diffusion of the BOP in any given year will be defined as the ratio of BOP steel produced to total steel produced by the steel industries of the countries under consideration, i.e., the U.S. and Canada. What were the determinants of changes in the level of diffusion for the two countries during the 1955 to 1970 period? What caused the different experience of the two industries with the BOP? The following paragraphs outline the determinants of the diffusion of the new technique in general.

The Amount of Investment. On the assumptions of perfect knowledge and foresight the diffusion of a new cost reducing capital embodied technique will depend on the amount of investment.[11] This statement really involves a tautology and no causaltiy can be inferred.[12] Hence, a more appropriate variable might be the age of the capital stock when the new innovation appears on the scene since this variable determines the amount of replacement investment, and therefore, is a more "ultimate" determinant of the diffusion of capital embodied techniques.

A high ratio of new invwstment to replacement investment would provide an additional stimulus to the diffusion of a new technique given that ancillary plant and equipment is more suitable to the older methods. For example, it has been argued that the cranes used with large OH furnaces were not readily adaptable to the smaller BOP furnaces.[13]

[11] For a rigorous theoretical treatment consult W. E. G. Salter, Productivity and Technical Changes, (second edition, Cambridge: University Press, 1966), pp. 48-65.

[12] But note the simultaneous nature of the relationship. Thus, an increased level of investment can lead to more rapid diffusion of cost reducing methods, improved competitiveness, increased demand, more investment and finally more rapid diffusion.

[13] McAdams, op. cit., pp. 466-67.

Relative Factor Prices. It has been argued that a high wage rental ratio will stimulate the search for labour saving techniques, and a low wage rental ratio will induce capital saving process innovations. However, an entrepreneur considering the adoption of a known process would be indifferent to a labor or capital saving bias provided only that the present value of his investment is greater than zero. This issue has led to some heated argument, but the matter is not very important in the present connection since the BOP saves on both capital and labor inputs per unit of steel output, and these savings appear to differ by insignificant amounts.[14]

While the relative factor input prices do not play a large role in the diffusion of the BOP, the relative prices of material inputs into the steel furnace (scrap and hot metal or pig iron) are of crucial importance. The rationale for this argument reflects the 50% scrap, 50% hot metal charge of the OH and the 30% scrap, 70% hot metal charge of the BOP. In other words, a low relative price of hot metal favours the diffusion of the BOP.

The Condition of the Industry. It is often suggested that unsatisfactory profits and low rates of capacity utilization will force oligopolists to become more innovative and reject familiar but obsolete methods.[15] However, the discipline of competition would not be felt with the same rapidity and effectiveness in industries

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[14]Data provided by Adams and Dirlam and Maddala and Knight differ somewhat in this respect. Adams and Dirlam suggest that the BOP has a slight capital saving bias while Maddala and Knight quote data which suggest that compared with the OH process the BOP process is "both capital and labor saving and further that technical change in this instance has been essentially neutral." Ibid., pp. 538-39. Note that the cost structure of the Canadian and U.S. steel industries do not differ radically from each other with wages and salaries representing 27.1% of total costs in Canada in 1954/55 and 35.1% of total costs in the U.S. in the same period. For the ECSC wages and salaries account for a lower portion of total costs. See McAdams, op. cit., p. 464 and American Iron and Steel Institute, Annual Statistical Report, New York: 1954, 1955.

[15]W. H. Haller, "Technological Change in Primary Steelmaking in the United States, 1947-65," The Employment Impact of Technological Change, (Washington: National Commission on Technology, Automation and Economic Progress, 1966), II-184 and II-185.

such as steel where the major firms have considerable market power as compared with perfectly competitive industries. Therefore, the correct relationship may not run from the current observed rate of capacity utilization to the diffusion of a new technique in the current period. Instead the divergence in capacity utilization from the long run norm or permanent capacity utilization may be the correct specification.[16] In other words, when observed capacity utilization falls below permanent capacity utilization efforts to reduce costs are increased and these efforts include the adoption of new techniques.

However, period of low capacity utilization would appear to be unfavorable for the introduction of new plant adding to existing capacity, and given that replacement investment may favor the continued use of older (although improved) techniques high rates of capacity utilization would stimulate diffusion of new processes. Therefore, it is impossible to specify a priori the correct sign of the relationships.[17]

Import Competition. Increased inroads by foreign competitors in the domestic market have been viewed as one source of discipline which insures the technological progressiveness of oligopolists in a particular country. However, the implication of the studies by Adams and Dirlam on the U.S. steel industry is that these inroads might have to be considerable in order to bring about a reaction by the major firms. Otherwise, these firms would simply view increased

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[16]The argument for this view is strengthened by the fact that capital equipment in the steel industry is long lived. I am indebted to Steve Globerman, York University for the suggestions on "permanent" capacity utilization.

[17]R. S. Thorn has pointed out to me that given the preference for price rigidity in the U.S. steel industry capacity utilization is really a policy variable for the major firms. In this case, low rates of capacity utilization might not be viewed as evidence of poor performance.

imports in the same way as they view an increased market share by the competitive fringe of the industry, i.e., as a minor nuisance which can be tolerated as long as the market share of imports or small domestic producers is not large.[18] In addition, the natural protection afforded by the high transport costs of foreign suppliers insulates domestic producers from foreign competition except in coastal areas.

An argument often made in the Canadian context revolves around the fact that producers will not enter product lines where the small domestic market makes only low volume production runs possible provided that trade barriers are below the prohibitive level. The implication of this view is that high imports do not necessarily reflect any lack of competitiveness, and therefore, would not affect the diffusion of new techniques.

The Market Structure of the Industry. Orthodox analysis suggests that the diffusion of a new technique will be most rapid under perfect competition. If one firm in the industry adopts a cost reducing method, competitors must do the same or else new entrants will drive the lagging firms into bankruptcy. Monopolists or oligopolists may develop new products and processes with large R&D programs, but they have a choice of adopting or not adopting new technology. At the very least, they have some discretion about the timing of their decision.[19] Nevertheless, the actions of rivals in an oligopoly situation will influence this decision, and hence, one may hypothesize that the degree of internal competitive pressure in an industry will affect the diffusion of new techniques. In fact, Mansfield after studying the rate of imitation (or interfirm rate of diffusion) for a number of innovations in the brewing, coal, iron and steel

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[18] On the expansion of the competitive fringe and the reaction or lack of reaction the major U.S. firms (especially U.S. Steel) see F. M. Scherer, Industrial Market Structure and Economic Performance, (Chicago: Rand McNally, 1970), pp. 168-70 and pp. 216-18.

[19] Salter, op. cit., p. 92.

and railroad industries concludes that "the rate of imitation is higher in more competitive industries, but there are too few data to warrant any real conclusion on this score."[20] On the other hand, Mansfield also notes that "small firms once they begin, are at least as quick to substitute new techniques for old as their larger rivals."[21] The degree of competitive pressure in the U.S. or Canadian steel industries would appear to depend on the actions of the major firms in the industry. If one of these major firms adopts a new technique, the others must either follow or if possible reduce costs with existing techniques. For the United States, it might have been argued at one time that the actions of U.S. Steel werethe deciding factor because the firm acted as a price leader. However, U.S. Steel has had a declining share of the market over time and the conventional wisdom now refers to the Giant Three or Big Eight.[22] Of the eight largest firms, Jones & Laughlin represents a special case as far as the BOP is concerned. The firm adopted the BOP already in 1957, but "was one of the slowest growing of the big eight, and less profitable than its most closely matched rivals."[23] Thus, Jones & Laughlin as well as its competitors "might well have viewed cost reducing innovations as a way of maintaining a threatened traditional position in the market, rather than of initiating a competitive move to improve it."[24] Thus, the pressure to adopt the BOP increased

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[20]Mansfield, op. cit., p. 144.

[21]Ibid., p. 191.

[22]Scherer states that the steel industry is the most prominent example of an industry where price leadership has deteriorated in recent years. (op. cit., p. 168). The discussion above assumes that reductions in costs through new techniques will ultimately lead to pressure on prices, but only when the major firms have reduced their costs. Frequent reference to the Giant Three and Big Eight is made by Haller.

[23]Haller, op. cit., II-185.

[24]Loc. cit.

substantially only when U.S. Steel as the second of the Big Eight adopted the method in 1963.

By contrast in Canada there are only four major firms (medium size by American standards) in existence; namely, STELCO, Algoma, DOFASCO and DOSCO, DOFASCO along with McLouth Steel of the U.S. pioneered the BOP in 1954, and hence, the competitive pressure on the major firms to adopt the technique or to improve the OH method was considerable right from the beginning. This factor, then, must be included in any discussion of the <u>difference</u> in the diffusion of the BOP between the U.S. and Canada.

The model suggested by the above discussion can be specified in the following way:

$$\frac{BOP_t}{TOT_t} \cdot 100 = \alpha_1 + \alpha_2 I_t + \alpha_3 SP_t + \alpha_4 CU_t + M_t/C_t + u_t$$

where

$(BOP_t/TOT_t) \cdot 100$	$\equiv$	% of steel ingot output as a proportion of total output in period t.
I_t	$\equiv$	gross investment in real terms in period t. (millions of constant dollars).
SP_t	$\equiv$	the ratio of average scrap prices per ton to average hot metal (or pig iron) prices per ton in period t.
CU_t	$\equiv$	capacity utilization in period t (the ratio of output to rated capacity).
M_t/C_t	$\equiv$	the ratio of imports to domestic consumption in period t.

The discussion above suggests certain alternative formulations for some of the variables. For example, CU_t can be replaced by CU_t' where the new variable equals $CU_t - \sum_{t=1}^{n} CU_t/n$ or the divergence between current period capacity utilization and the long-run average capacity utilization. In addition, the dependent variable might be altered to $(BOP_t/BOH_t) \cdot 100$ where BOH_t refers to the amount of steel produced with the basic oxygen and open hearth method alone.

This would exclude steel produced with electric reduction methods from the denominator on the assumption that this method for making specialty steels is not in direct competition with the BOP and OH methods.

The theories underlying the above equation are quite general, and hence, the equation can be estimated from data on the U.S. and Canadian steel industries in the 1955-69 period. In addition, the following dependent variable $[(BOP_t/TOT_t)]_{CAN} - [(BOP_t/TOT_t)]_{US}$ is specified in order to explain the somewhat different experience of the two countries with the BOP. The independent variables are then introduced in terms of the Canada-U.S. ratio, i.e., the greater the amount of investment in Canada relative to the U.S. the greater would be the expected diffusion of the BOP etc. In accordance with a previous argument, a dummy variable which takes on the value of zero for all years from 1955 to 1962 and one from 1963 to 1969 is introduced in order to reflect the adoption of the BOP by U.S. Steel at that time.

Representative results for the above model using the Ordinary Least Squares regression method are given in Table I. In general, these results judged by the goodness of fit and significance of variables criteria are encouraging. In all cases, over 80% of the variation in the dependent variable has been explained by changes in the independent variables, and in addition, the investment and scrap price variable are significant at the 1% level with the exception of one equation for the U.S. where the scrap price is significant at the 5% level.

However, several anomalies are immediately apparent. Thus, the scrap variable although significant has the "wrong" sign since we hypothesized that a high price of scrap relative to hot metal or pig iron would lead to a more

Table I - Econometric Results for the

BOP Diffusion Functions, 1955-69

Dependent Variable	I	SP	CU	CU′	M/C	DUM	CON	d.f.	R^2	DW
$(BOP/TOT)_{CAN}$	+0.089 (3.908)**	-0.495 (4.389)**	-0.162 (0.854)				+36.97 (2.516)*	11	.851	1.36
	+0.088 (3.908)**	-0.495 (4.389)**		+ 0.162 (0.854)			23.88 (4.033)**	11	.851	1.36
LOG FORM	+0.973 (4.424)**	-0.639 (3.325)**	-1.638 (1.863)				7.47 (2.016)	11	.833	1.25
$(BOP/BOH)_{CAN}$	+0.098 (3.864)**	-0.585 (4.658)**	-0.181 (0.858)				42.57 (2.600)*	11	.858	1.45
$(BOP/TOT)_{US}$	+0.025 (4.346)**	-1.046 (5.439)**	+0.349 (1.833)				- 8.436 (0.699)	11	.852	1.60
	+0.025 (4.346)**	-1.046 (5.439)**		-(0.349) (1.833)			18.04 (1.809)	11	.852	1.60
	+0.015 (3.932)**	-0.306 (2.085)*			2.912 (5.857)**		- 8.03 (1.440)	11	.953	1.13
LOG FORM	+3.001 (4.162)**	-4.514 (5.954)**	-1.575 (0.976)				2.89 (0.444)	11	.852	2.14
$(BOP/BOH)_{CAN}$	+0.028 (4.197)**	-1.205 (5.303)**	+0.411 (1.828)				-10.30 (0.69)	11	.845	1.53
$[(BOP/TOT)]_{CAN}$ / $[(BOP/TOT)]_{US}$	+145.9 (4.930)**	+39.05 (3.914)**			-0.319 (1.380)	-8.107 (2.739)*	-35.8 (3.758)**	10	.898	2.20

$[(BOP/TOT)]_{CAN} - [(BOP/TOT)]_{US}$

** Significant at the 1% level, one tail test.
 * Significant at the 5% level, one tail test.

rapid diffusion of the BOP.[25] Note, however that the increased use of the BOP will have a depressing effect on the price of scrap because the furnace charge is only made up of 30% scrap as opposed to 50% with the OH. Therefore, as the use of the BOP becomes widespread scrap prices will tend to fall relative to pig iron or hot metal prices and this simultaneous relationship would appear to explain the "wrong" sign. On the other hand, a look at the Canada-U.S. equation confirms that periods when Canadian scrap prices were high relative to their U.S. counterparts are associated with a more rapid diffusion of the BOP in Canada. Another point which should be remembered is that the lower scrap prices connected with the adoption of the BOP will ultimately act as a drag on further adoption of the process since the use of the OH method (and especially electric furnaces) becomes more attractive. However, the magnitude of this effect is minor compared with the labour and capital cost savings of the BOP, and moreover, an alternative response involves alterations to BOP technology.[26]

For both Canada and the U.S. the capacity utilization variable independently

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[25] Certain data problems should also be mentioned. For example, existing hot metal prices are estimates of intrafirm prices. Therefore, it was necessary to rely on pig iron prices, but these do not necessarily reflect input costs for most firms which rely on hot metal produced in their own integrated facilities. Moreover, the Canadian pig iron price series shows almost no variation, and hence, the price of scrap alone varies.

[26] For example, if the price of scrap fell from \$36.00 to \$30.00 and the OH furnace uses one-half a ton of scrap and the BOP furnace one-third a ton, then cost savings achieved are \$3.00 for the OH and \$2.00 for the BOP. This should be compared with a labour cost saving with the BOP of \$5.00 a ton. See Adams and Dirlam _op_. _cit_., p. 179.

of the particular formulation used fails to be significant at the 5% level in a two tail test.[27] This suggests that firms do not respond in any consistent way to high or low rates of capacity utilization. However, it is possible that this variable is subject to measurement errors,[28] and that alternative indicators of the general condition of the industry might be desirable.

Another problem of interpretation exists with the market penetration by imports variable which failsto be significant for Canada (results not presented in Table I), but is significant at the 1% level for the U.S. The best results for the U.S. occurred with a three year lag on the import variable, and this suggests that the U.S. industry responded although slowly to the import competition which was already apparent in 1959 when imports rose to 6.1% of domestic consumption from the 2.7% registered in the previous year.[29]

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[27]The two tail test is used for this coefficient because the correct sign could not be specified à priori.

[28]After 1960, the American Iron and Steel Institute no longer published data on capacity in the U.S. steel industry. Therefore, the capacity utilization series is based on rough estimates found in the sources listed in the statistical appendix. However, Canadian data on this variable appear to be reliable--one suspects because they are less embarassing than the American data to the industry.

[29]Data are from American Iron and Steel Institute, Annual Statistical Report. Note that the import variable appears to dominate this equation and reduces the importance of both the investment and scrap variable. Before anyone concludes that the basic causal relationship runs from import competition to diffusion of the BOP the critical comments made by one economist with respect to regressions embodying the Phillips curve should be noted. In other words, it may be that only a "contingent" and not a "causal" relation between import movements and BOP adoption is involved. See E. H. Phelps Brown, "The Underdevelopment of Economies," Economic Journal, 82(March 1972), pp. 5-6.

The difference between the Canadian and U.S. experience with respect to the role of import competition may appear surprising, but there is no reason to expect any influence of imports in the Canadian case given the early adoption and rapid diffusion of the BOP prior to the mid-sixties. Moreover, Canadian producers have a passive strategy toward imports as long as these are not large in particular product lines. In other words, the commodity composition of imports provides information which tells producers which product lines should be added to their output without facing the high costs of small scale production. Of course, this strategy only works when domestic producers are competitive at the world price plus transport and tariff costs. The statement, "We don't worry about imports" which is sometimes heard in Canadian steel circles should be interpreted in the light of the above comments.

The Canadian and U.S. experience also differ with respect to the role of the internal competitive pressure variable, but this was predicted since one of the major Canadian producers first adopted the BOP[30] while no major U.S. producer did until 1963. Thus, the coefficient on the dummy variable which acts as a proxy for internal competitive pressure is significant with a negative sign, and hence, explains the elimination of the Canadian lead in BOP adoption. Previous diffusion models have sometimes attributed the increased rate of diffusion after a certain time interval to a "bandwagon" effect but this term is only descriptive and does not explain the timing of the increased rate of diffusion. The different experience of one oligopoly as compared with another

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[30] In 1956, DOFASCO which was the first Canadian firm to adopt the BOP produced 12.2% of total Canadian crude steel production, and by 1960 this figure had risen to 17.4%. Therefore, this firm was a major producer and used technological developments in an aggressive bid to increase her share of the market.

probably indicates that such statements as "it may well be that the structural and behavioral characteristics of oligopolized industries prevent the dominant firms from innovating" are too sweeping.[31] However, Vernon's view that "any threat to the established position of an enterprise is a powerful galvanizing force to action"[32] receives partial confirmation from the empirical results. The actions of powerful rivals as opposed to those of a member of competitive fringe on technological matters apparently are not ignored. Vernon emphasizes the point by concluding that "threat, in general, is a more reliable stimulus to action than opportunity is likely to be."[33] On the other hand, Mansfield has found that the profitability of a technique is a major determinant of the rate of diffusion of a technique.[34] This raises the possibility that the BOP was more profitable in the Canadian environment prior to 1963, and that subsequently, the BOP became relatively more profitable in the U.S. The first part of this hypothesis is examined in the following section.

IV. Alternative Explanations for the Diffusion of the BOP in Canada and the U.S.

Both the theoretical discussion and the econometric results indicate that there may be additional factors which explain the different time pattern of BOP diffusion in Canada and the U.S.[34A] The existence of conversion costs

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[31] Adams and Dirlam, op. cit., p. 188.

[32] Raymond Vernon, "International Investment and International Trade in the Product Cycle," Quarterly Journal of Economics, 80 (May 1966), p. 200.

[33] Loc. cit.

[34] Mansfield, op. cit., pp. 190-91.

[34A] Some of these factors are contained in the controversy between Adams and Dirlam on the one hand, and McAdams on the other. See A. K. McAdams, "Big Steel, Invention and Innovation, Reconsidered," and W. Adams and J. B. Dirlam, "Big Steel, Invention and Innovation: Reply," Quarterly Journal of Economics, 81 (August 1967), pp. 457-32.

and the problems of interrelatedness tend to reduce the profitability of replacing OH furnaces with BOP furnaces in existing steelmaking plants. These difficulties do not arise when entirely new plants are being constructed from the ground up.[35] The number of entirely new plants being built depends on the age of existing plants and the growth of the industry. Unfortunately, data on the age of plants in the U.S. and Canada during the mid-fifties are not readily available. However, the annual compound growth rate of consumption of steel products was 0.1% for the U.S. and 3.1% for Canada between 1956 and 1970, and this would appear to mean that investment in a new capacity was higher in Canada than the U.S.[36] However, technological progressiveness which leads to improved cost and price competitiveness can bring about increased demand either through the substitution of steel for other materials or the substitution of imports and increased exports. Thus, Canadian production increased by 6.0% per annum as compared with 0.6% in the U.S. during the above period, and the ratio of new investment to replacement investment was probably an effect as well as a cause of the rate of adoption of the BOP.[37]

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[35] For a systematic treatment of this hypothesis consult E. Ames and N. Rosenberg, "Changing Technological Leadership and Economic Growth," Economic Journal (March 1963), pp. 13-31.

[36] Data on consumption and production of steel products are from American Iron and Steel Institute, Annual Statistical Report and Dominion Bureau of Statistics, Primary Iron and Steel, Ottawa: selected years.

[37] The fact that between 1955 and 1960 the amount of OH capacity added in the U.S. amounted to 14.9% of U.S. capacity, and that the equivalent figure for Canada was only 10.8% is not directly relevant since we do not know whether this capacity was added in existing plants or new plants. For data sources see fn. 36 and Table II.

Another possibility is that the ratio of scrap prices to hot metal or pig iron prices should be replaced by an availability variable since a shortage of hot metal may have prevented some firms from adopting the BOP. The installation of additional blast furnace capacity to produce hot metal would add to production costs with the BOP. However, blast furnaces in both the U.S. and Canada were considerably underutilized during the 1950's as Table II indicates. Nevertheless, a shortage of hot metal may have prevented some firms from adopting the BOP because pig iron which could be obtained from firms with excess blast furnace capacity is more expensive than hot metal and must be reheated prior to being charged into a steel furnace. For example, the price of pig iron was $50-69 a ton in the U.S. in 1965 while the estimated intrafirm price of hot metal was $35-39 a ton.[38] Although excess capacity in

TABLE II

Capacity Utilization for Blast Furnaces in the U.S. and Canada

Year	CANADA	U.S.
1952	75.3%	84.2%
1954	54.2%	71.6%
1956	80.9%	88.9%
1958	68.3%	63.5%
1960	82.5%	69.7%

Sources: Canada: G. E. Wittur, Primary Iron and Steel in Canada, Department of Energy, Mines and Resources, Mineral Information Bulletin MR92 (Ottawa: Queen's Printer, 1968).

U.S.: American Iron and Steel Institute, Annual Statistical Report, Washington, D.C., Selected Years.

[38] Haller, *op. cit.*, II-177.

the blast furnaces of both countries would indicate that the importance of this factor as a determinant of differences in diffusion was minimal individual firm data would be necessary for a rigorous test of the hypothesis.

Since some countries with small scale steel plants (notably Austria) have been leaders in BOP adoption, it is suggested that the BOP tends to be more cost saving at a smaller scale of operation. The average scale of steel plants in Canada as compared with the U.S. was smaller in 1954 before the arrival of the BOP, but not by any substantial amount. For example, 40% of Canadian and 50% of U.S. capacity consisted of plants which exceeded the one and a half million ton size and the average capacity of OH furnaces was 138 tons and 136 tons in the U.S. and Canada respectively at that time.[39] Moreover, cost reductions as scale increases would seem to be higher for the BOP than the OH furnace at least for plants in the 500,000 to one million ton range where the ratio of total costs of an OH plant as compared with a BOP plant stands at 1.36 and 1.45 respectively.[40]

Although there is a great deal of controversy on this subject, it is suggested by some researchers that the BOP was not suited for producing steel for purposes other than flat rolled products until the early sixties. It follows that the BOP would be more profitable for firms in a country where the demand for sheet and strip is relatively large. Data on market demand by type of product indicate that this argument has little relevance in the Canada-U.S. framework. For example in 1961, sheet and strip amounted to 38.9% of U.S. steel shipments

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[39] Ibid., Appendix, and Department of Energy, Mines and Resources, Primary Iron and Steel, Operators List 1, Part 1, Ottawa: 1955.

[40] Based on data from Adams and Dirlam, op. cit., p. 34.

and 41.3% of total Canadian steel shipments which indicates that the product mix differs little between the two countries.[41]

Another technical difficulty with the BOP is that it did function well when the phosphorus content of the iron ore used in making hot metal was high, i.e., in excess of 0.4% by weight of iron ore charged into the blast furnace. The main sources of ore for U.S. mills are the Mesabi Range (Minnesota), Quebec-Labrador and Venezuela while for Canada they are the Mesabi Range, Northern Ontario and Quebec-Labrador. These ores are not high in phosphorus content. For example, the ore from the Mesabi range generally has less than 0.1% phosphorus content, and hence could not have held up the adoption of the BOP in the U.S. or Canada.[42]

The discussion of this section has failed to reveal any additional factors which might explain the more rapid diffusion of the BOP in Canada from 1955 to 1964. Further research may show that the above variables played a role in determining which particular firms first adopted the BOP. In addition, factors such as the effectiveness of the R & D effort of the U.S. and Canadian steel industry in transferring new technology from other countries and adapting it to local conditions as well as the quality of entrepreneurship may have had an effect on the rate of diffusion of the BOP.[43]

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[41] For data sources see fns. 33 and 34. It should also be mentioned that DOFASCO which adopted the BOP in 1954 has a product mix which is biased toward flat rolled products while Algoma (BOP adopted 1958) concentrates on structurals. Yet in a letter dated August 9, 1972, B. W. H. Marsden of Algoma wrote: "Within two months of start up, the (BOP) shop was producing all grades of steel normally produced in the Open Hearth Shop, including low alloy steels and steel up to 1% C.

[42] Data on chemical analysis of ores provided by Algoma Steel. See also United Nations, Survey of World Iron Ore Resources, New York, 1955.

[43] Note that BOP was first applied in Austria, and that the first use of the technique in North America took place in 1954 by McLouth Steel of Detroit and DOFASCO of Hamilton, Ontario. Hence, the resources devoted toward developing new products or processes are not the crucial factor. For greater detail consult H. G. Baumann, op. cit., pp. 75-82 and pp. 90-94.

V. Conclusion

The present study has been restricted to the diffusion of one particular technique, and therefore, any policy implications may be of limited relevance. If the rate of diffusion of new techniques in an industry is judged to be too low in the sense that the economic performance of the industry is detrimentally affected or, more elegantly, the discounted sum of profits and consumer surplus through time is not maximized,[44] then an increased volume of investment and increased competitive pressure on the industry would contribute toward the goal of dynamic efficiency. But several caveats should be kept in mind in this regard.

Since the rate of diffusion of new techniques may differ considerably from one oligopoly situation to the next, vigorous antitrust actions would not appear to be a cure-all for a lack of dynamic efficiency.[45] This is especially true when antitrust policy relies on concentration ratios to measure the scope of discretionary action by the largest firms of the industry. Thus, almost any measure of concentration will show that the Canadian steel industry is more

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[44] In order to make this concept operational, estimates of the cost curves with various techniques as well as the demand curve are required. The difficulties involved in this exercise have led to the use of price and export performance as criteria. Needless to say, the latter approach is imperfect and must be used with caution since economic opportunities differ from one country to the next. See. J. S. McGee, In Defense of Industrial Concentration (New York: Praeger, 1971), p. 100.

[45] In other words, the degree of competitive pressure would appear to have qualitative aspects. Although the inertia of the large U.S. firms in adopting the BOP suggests that a policy of breaking up some of these firms might be desirable, there is no guarantee that the dismembered parts of U.S. Steel, Bethlehem, Republic, etc., would have acted like the smaller steel producers, i.e., adopted the BOP quickly. See also McGee, *op. cit.*, pp. 127-37.

concentrated than the American steel industry. For example, in 1962, the four largest Canadian and American firms produced 74% and 59% of the total steel output in their respective economies.[46] Yet it obviously does not follow that the major U.S. firms have less market power. The only way to assure dynamic efficiency in the long-run would appear to lie in the possibility of large scale entry by progressive firms, but no mechanisms which might assure this result exist at the present time.[47] The only exception to this rule is the entry of subsidiaries of foreign firms into the domestic market.

Canadian economists have stressed the importance of competition from imports to assure the efficient allocation of resources, but the case of the BOP casts some doubt on the contention that dynamic efficiency can be maintained in this way because the U.S. industry appears to have reacted to increased imports with a considerable lag.

However, it can be argued that the emphasis on competitive pressure to improve dynamic efficiency is misplaced. Thus, economic theory and empirical research appear to support the contention that perfect competition will lead to the fastest diffusion of known techniques.[48] Of course, this is

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[46] For additional concentration measures consult Department of Consumer and Corporate Affairs, Concentration in the Manufacturing Industries of Canada (Ottawa: Information Canada, 1971), Table A-13. At one time, U.S. Steel dominated the American steel industry, but there is little evidence to suggest that this firm is at present more powerful than STELCO relative to other Canadian producers.

[47] In a recent article R. M. Cyert and K. D. George conclude that we cannot rely on the competitive pressure of the market to ensure efficiency in firms, and hence, mechanisms which act directly on managers must be found. However, their discussion apparently does not deny the beneficial impact on the rate of diffusion of new methods of a progressive firm which is one of the dominant forms of an oligopolistic industry. Furthermore, the possibility of increased growth through exports or import replacement might be one of the factors which induce management to set higher goals, and thus initiate the search for cost reducing methods. See their "Competition, Growth and Efficiency," Economic Journal, 79 (March 1969), 40-41.

[48] Salter, op. cit., p. 92 and McGee, op. cit., p. 101.

only true when the size of the innovation is not large relative to the size of the economic units involved and so on. But leaving these imperfections aside, there is the more important difficulty, namely that perfect competition will not lead to the optimal amount of expenditures on the development of new products or processes because private costs and benefits will diverge.

This line of reasoning implies a trade-off between the rapid diffusion of known techniques and the development of entirely new techniques. However, for a single economy especially if it is small relative to the rest of the world, this trade-off does not really exist because even with a sizable and efficient R&D effort the number of new processes discovered and developed will be few relative to the rest of the world.[49] Hence, the aim should be to increase the efficiency of the mechanisms through which discoveries made elsewhere are transmitted to the industry of the economy in question. An argument can also be made for expenditures which adapt these discoveries to local economic conditions. These expenditures will increase the rate of acceptance of the technique given the existence of competitive pressures.

The empirical results also indicate that increased investment would increase the rate of diffusion of capital embodied techniques such as the BOP. Therefore, the use of investment tax credits to improve dynamic efficiency could be considered. The problem with this particular policy is that no distinction is made between differences in the quality of the equipment required. Thus, a BOP or an OH furnace are equivalent from the tax credit point of view. Indeed, investment tax credits would tend to favour the retention of the older OH technique because the BOP has a slight capital saving bias. Therefore,

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[49] In 1963, 69.8% of all patents granted in Canada were of U.S. origin while 24.7% were of other foreign origin which leaves 5.5% as originating in Canada. For the U.S., the same conditions do not apply, but for some industries such as steel, a considerable number of innovations occur outside North America. See O. J. Firestone, Economic Implications of Patents (Ottawa: University Press, 1971), pp. 373-74.

the use of such credits will not affect the rate of diffusion of new techniques directly.

Therefore, although this case study has been suggestive with regard to the determinants of the rate of diffusion of new techniques, further studies of other industries are required in order to determine whether or not these observations have general applicability and can form the basis for any policy conclusions.

Statistical Appendix

Sources for the data on some of the variables, notably the dependent variables in the regressions have been mentioned in the text. The sources for data on other variables are presented below:

I_t ≡ Data on gross investment for the U.S. are from American Iron and Steel Institute, Annual Statistical Report, 1955-1969. This series was deflated by the implicit price index of the producers' durable equipment component of gross private domestic investment from the U.S. Department of Commerce, Survey of Current Business. Canadian data are from V. B. Schneider, Canadian Primary Iron and Steel Statistics to 1969, Department of Energy, Mines and Resources, Ottawa, 1971. The implicit price index for new machinery and equipment from Dominion Bureau of Statistics (now Statistics Canada), National Accounts, Income and Expenditure was used to deflate the series. Both capital and repair expenditures were included and the removal of the repair component of the series had only a minor impact on the results for the Canadian BOP diffusion function.

SP_t ≡ Scrap prices in local dollars per gross ton are from Steel Magazine. For the U.S. a composite index for No. 1 heavy melting steel scrap at Pittsburg, Chicago and Eastern Pennsylvania was used while for Canada the same series is based on Hamilton prices only. The same data source was also used for pig iron prices per gross ton.

CU_t ≡ Capacity Utilization data for the U.S. and Canada are from J. Singer, Trade Liberalization and the Canadian Steel Industry (Toronto: University Press, 1969). Additional Canadian data are from Department of Energy, Mines and Resources, Primary Iron and Steel, Operators List, Part 1.

M_t/C_t ≡ Data on imports and apparent consumption for the U.S. are from American Iron and Steel Institute, Annual Statistical Report. Canadian data are from G. E. Wittur, Primary Iron and Steel in Canada, Ottawa, 1968 and V. B. Schneider, Canadian Primary Iron and Steel Statistics to 1969, Ottawa, 1971.